MATERIALS PROCESSING

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SURFACE DIAMOND-ABRASIVE GRINDING OF GLASS WITH TOOLS BASED ON PLATE ELEMENTS: ROUGH GRINDING

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This paper considers the working capacity of diamond-abrasive circular tools based on plate-like elements or radially oriented spots used in industrial conditions for rough grinding and infeed milling of optical glass surfaces and other brittle materials.

Combined diamond-abrasive tools are extensively used in making parts from optical, quartz, or technical glass, glass ceramics, optical ceramics, and other brittle materials. The removal of allowance from flat blank surfaces is performed on various milling machines, as a rule, on surface grinders 3D756, 3B756, and BSZ-52 with tables of diameters 0.8 and 1.0 m. Treatment is performed using a circular tool with a discontinuous working surface in the form of a wheel with plate-like diamond-abrasive elements inserted on a base with their narrow ends along the periphery of the wheel body, in two versions.

When parts are placed along the entire rotary table, the treatment is performed feeding the tool from above in accordance with the operating scheme of the surface grinder. In this case the tool of diameter 566 – 510 mm has the peripheral working zone with elements of height 20 – 40, length 12, and width 1.5 – 4 mm arranged in a single row with grooves for removing lubricant-coolant and slime. Fixing 52 – 152 elements with a uniform angle pitch ensures the filling of the working zone with a space factor of 0.05 – 0.15. A rotational speed of the table equal to 10 – 30 min^{-1}, a tool speed of 980 min^{-1}, a tool feed of 0.15 – 1.50 mm, and diamond powder grains ranging from 250/200 to 630/500 provide for the removal of 540 – 5400 cm^3/min with roughness R_z = 60 – 160 μm.

The coarse infeed grinding (milling) mainly of faces and bevels of large-size parts was performed on a 3B161 cylindrical grinder modified for face grinding using single-row wheels of diameter 200 – 350 mm with the above specified parameters of diamond elements. The longitudinal feed is 70 – 150 mm/min with an infeed depth of 0.5 – 3.0 mm and a rotational speed of the tool equal to 1300 min^{-1}.

When the treated parts are fastened in special fixing devices placed along the peripheral zone of the rotary table of the specified surface grinders, treatment is performed using a double-row tool of diameter 510 mm. The plates with diamond-abrasive grain of fraction 315/250 and the finer size (160/125) are placed along the periphery of the wheel base in two concentric rows displaced to a half-step width, their grain size and height increasing from the center toward the periphery so that the working surfaces form conical-profile elements (USSR Inventor's Certif. No. 1349986). Using this design of the tool, the bulk of allowance (up to 3 – 4 mm) is efficiently removed by the first row of the elements. The second row with the smaller grain size removes the disturbed layer of material within the limits of 0.2 – 0.3 mm and creates roughness of R_z = 40 μm. This operating regime with the rotational speed of the tool equal to 980 min^{-1} and the speed of the table 0.14 – 0.20 min^{-1} is used to treat end faces and bevels of parts of size 100 – 200 mm. To work in the specified mode, surface grinders have been modified by installing a universal gearbox ensuring smooth control of the table rotation [1].

The vertical placement of the plates on their narrow side of width 1.5 – 4.0 mm spaced with an interval equal to their 5 – 10 thicknesses is implemented in a special mold (USSR Inventor's Certif. No. 487756). The elements are fixed in a fixing layer of thickness 0.2 – 0.3 mm, in particular, a layer of modeling clay applied to the bottom of the mold. Next, the tool body is placed in the mold and fixed, after which the tool inner cavity is filled via openings with self-solidifying plastic AST-T with suspension concentration of 1.25 – 1.50. To facilitate opening during operation and to raise wear resistance, an abrasive filler is introduced in the binder, such as electrocorundum, whose grain size and quantity corresponds

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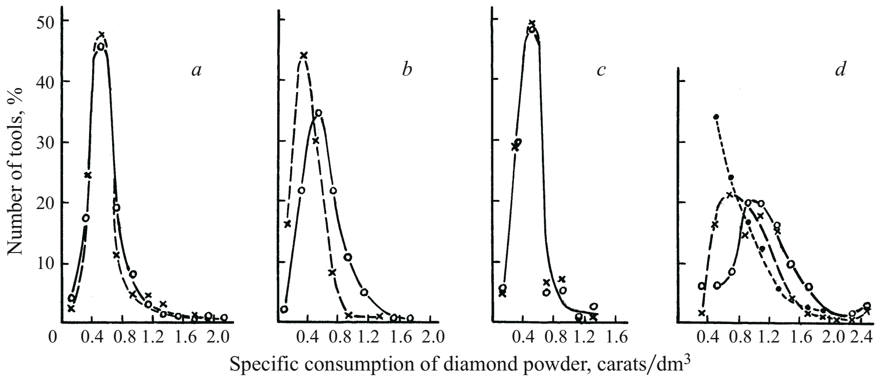

Fig. 1. Normal distribution density curves of diamond consumption in rough grinding using plates with powders AS15 (○), A_3D (×) of grain size 400/315 and concentration 100% (*a*, *c*) and 50% (*b*) on faceplates of diameter 566 – 510 mm (*a*, *b*) and 350 – 200 mm (*c*); using wheels with spot-like elements on powders AS15 (○), AS20 (×), AS32 (●) of grain size 160 – 125 and concentration 50% on binder M3-12 (*d*).

to that of the diamond powder used in the elements (USSR Inventor's Certif. No. 921837). After the polymerization of the plastic, the tool body with fixed elements is pressed out.

For rough grinding of surfaces, we used plate-like elements on metallic binder M1-1 (10, 20, and 70 wt.% tin, nickel, and copper, respectively) and partly on binder M2-01 (previously graded M1) (20 and 80% tin and copper). The rated hardness of the binder being equal to 45 units, its actual hardness varied in the range of 37 – 85. Cooling was performed with pure water with 0.5 – 1.0% technical lignosulfonate added [2].

Records of the manufacture and service of each tool have made it possible to accumulate data on their working capacity in industrial conditions during 25 years (1973 – 1998). The data were obtained in grinding parts (of different sizes and thickness) made of different grades of glass with a corresponding spread in hardness values under possible accidental deviations from the milling regimes. The data analysis processed up to 97 – 95% of each grade and variation grain sizes and concentration of diamond powders that have been used for industrial purposes.

The results of data processing for rough grinding are presented in Table 1 and in Fig. 1. The reference powders used in the tools are synthetic diamond powder AS15 and natural A_3D with grain size 400/315 and concentration 100 and 50%. Using the tool of diameter 566 – 510 mm, the average specific consumption for three out of the four main powder compositions is virtually identical. In the case of 100% concentration, the average specific consumption of natural diamond is approximately 5% lower than that of synthetic diamond with the similar dispersion (Fig. 1*a*). With 50% concentration, the advantages of natural diamond powder are more significant (its mean specific consumption is 60% lower) and, accordingly, the value of the variance (Fig. 1*b*) is shifted toward a lower specific consumption compared to synthetic powder.

In the case of 100% concentration, using diamond powder of a lower grain size (315/250) increases the average specific consumption 1.76 and 1.34 times for synthetic powders AS15 and AS20, respectively, compared to powder AS15 of grain size 400/315 and 2.13 times compared to natural powder A_3D. A further decrease in the grain size to 250/200 raises specific consumption even more, increasing it, respectively, 2.05 (1.18) and 1.66 (1.23) times for synthetic powder and 2.21 (1.04) times compared to the reference grain size of 400/315 (the increase compared to the grain size of 315/250 is indicated in brackets). It can be seen that natural diamond powder under the specified conditions is equivalent to synthetic powder or even less efficient. For higher-strength and less defective powders [3, 4] such as AS50 and A8 of grain size 400/315, A_3D of grain size 500/400, and A of grain size 600/400 the average specific consumption compared to three basic compositions is lower by 11 – 20% and for powder AS65 of grain size 400/315 it is lower by up to 36%.

In the case of 50% concentration for diamond powders AS65 and RKh1 of grain size 400/315 and A_3D of grain size 315/250 and 500/400 the average specific consumption is 20 – 30% lower than the reference composition with diamond AS15, and for powders AS50 and AS65 with grain size 315/250 the specified parameter is lower by 5 – 10%. However, the first group of compositions has 1.27 – 1.12 times higher values than the average specific consumption using natural powder A_3D and the second group is 1.5 times higher. Note that the tool with diamond AS32, which is stronger than AS15, however, has the same mean specific consumption.

In the case of 75% concentration of powder AS32, its average specific consumption is also abnormally higher than in an analogous composition with powder AS20 and 10% lower than in the analogous composition with 100% diamond concentration.

The data on the mean specific consumption for 25% concentration and grain size 250/200 are 1.07, 1.28, and 1.37 times higher than the tool with 50% concentration and grain size 400/315 for powders AS15, AS65, and RKh1, respectively. For 50% concentration and grain size 315/250 the specific consumption of powders AS50 and AS65 are 1.25 and 1.1 times higher. At the same time, in the case of 100% concentration and identical grain size (250/200) the mean specific consumption of diamond powder AS15 is 1.9 times lower and that of AS20 powder with 12.5% concentration is half as much.

Thus, in rough grinding using tools of diameter 566 – 510 mm, about 70% data of average specific consumption are within the limits of 0.65 carats/dm^3, which is prescribed

in the norms and specifications for a wide range of diamonds powder grades and fractions (OST3-6324–87) [5]. However, even in the case of using the specified compositions, the specific consumption for some tools is triple the prescribed value (Table 1).

It is appropriate to recuperate diamond powder extracted from worn elements by pickling them in concentrated hydrochloric and nitric acids (grade RKh) and melting in prescribed crucibles at a temperature of 700 – 1400°C depending on the type of the binder (grade RF). The classification of recuperated powders demonstrated that they have unaccounted for ratios between synthetic and natural diamonds.

All compositions in the tool with 50% diamond powder concentration have average specific consumption within the limits of the standard requirements mentioned. For compositions A_3D and RKh1 of grain size 400/315 and A_3D of grain size 315/250 the majority of tools (93.1, 86.4, and 88.8%) as well have specific consumption below 0.65 carats/dm^3. On this basis this particular concentration is generally preferable to 100% concentration.

The values of the average specific consumption of powders with 25 and 12.5% concentrations and grain size 250/200 also corroborate the efficiency of tools based on these compositions; furthermore, these particular diamond powder compositions can lower the production cost of the tools.

In industrial practice it is necessary to take inventory and periodically analyze each tool to estimate its operating capacity and the quality of diamond powder used.

The results for the tool 1 m in diameter were obtained on VSZ-45M surface grinder with a table of diameter 2 m in grinding parts over 1 m in diagonal. Diamond-abrasive heels of size $40 \times 80 \times 28$ mm were uniformly fastened with screws along the periphery with space factor of the working surface equal to 0.2 – 0.3. The heels themselves with plates based on purchased recuperated powder (grade RA) and binder M1-1 had space factor about 0.5. The rotational speed of the tool was 750 min^{-1}, and that of the table was 10 – 15 min^{-1}.

Working with a tool of diameter 350 – 200 mm in milling on upgraded 3B161 machine, the tendency for reference compositions in several parameters is similar to the trend observed in the tool of diameter 566 – 510 mm: the average specific consumption of natural diamond is lower than that of synthetic diamonds by about 5%; the specific consumption variance curves coincide in their shapes and values (Fig. 1*c*). However, the mean specific consumption of powder in the wheels of diameter 350 – 200 mm is lower by 18% for equal compositions and the maximum specific consumption is the double of its mean value. For this tool and these operating conditions the 50% concentration is more efficient as well: the average specific consumption is 24% lower for the particular wheel diameter with 100% diamond content and by 38% lower for faceplates of diameter 566 – 510 mm of the analogous composition (powder AS15 of grain size 400/315, concentration 50%). The minimal average specific consumption of powder in this case is 0.36 – 0.38 carats/dm^3.

TABLE 1

Diamond powder: grade	Diamond powder: grain size	Diamond powder: concentration, %	Number of tools considered, units	Specific consumption of diamond powder, carats/dm^3: average	Specific consumption of diamond powder, carats/dm^3: range
Grinding (tool diameter 566 – 510 mm)					
A_3D	400/315	100	225	0.546	0.13 – 1.83
A8	400/315	100	9	0.487	0.37 – 0.71
AS15	400/315	100	443	0.577	0.12 – 2.04
AS50	400/315	100	11	0.462	0.29 – 0.63
AS65	400/315	100	12	0.372	0.28 – 0.40
RKh1	400/315	100	7	0.543	0.34 – 0.93
A_3D	315/250	100	30	1.163*	0.28 – 2.32
AS15	315/250	100	61	0.997*	0.15 – 2.15
AS20	315/250	100	84	0.775*	0.16 – 2.12
A_3D	250/200	100	19	1.210*	0.12 – 2.25
AS15	250/200	100	11	1.182*	0.35 – 2.03
AS20	250/200	100	13	0.957*	0.37 – 2.65
A_3D	500/400	100	7	0.461	0.33 – 0.63
A	600/400	100	13	0.465	0.33 – 0.56
RA**	800/630	100	23	0.840*	0.44 – 1.35
AS20	250/200	75	13	0.863*	0.54 – 1.56
AS32	250/200	75	13	0.925*	0.33 – 1.30
A_3D	400/315	50	87	0.362	0.12 – 0.89
AS15	400/315	50	184	0.581	0.13 – 1.70
AS32	400/315	50	76	0.612	0.11 – 2.05
AS65	400/315	50	27	0.460	0.18 – 1.29
RKh1	400/315	50	44	0.443	0.12 – 1.67
A_3D	315/250	50	27	0.428	0.11 – 0.99
AS50	315/250	50	8	0.554	0.32 – 0.80
AS65	315/250	50	23	0.531	0.21 – 1.23
A_3D	500/400	50	13	0.405	0.20 – 0.63
AS15	250/200	25	58	0.620	0.24 – 1.89
AS50	250/200	25	20	0.695*	0.30 – 1.73
AS65	250/200	25	88	0.588	0.12 – 1.76
RKh1	250/200	25	236	0.610	0.10 – 1.06
RF1	250/200	25	43	0.684*	0.10 – 1.61
AS20	250/200	12.5	10	0.464	0.14 – 1.37
Milling (tool diameter 350 – 200 mm)					
A_3D	400/315	100	119	0.451	0.14 – 1.20
AS15	400/315	100	173	0.473	0.12 – 1.38
AS65	400/315	100	23	0.380	0.21 – 1.20
RKh1	630/500	100	25	0.715*	0.33 – 0.94
AS15	400/315	50	12	0.362	0.11 – 0.49
AS15/AS20*** AS15***	315/200 160/125	100 50	292	1.430*	0.35 – 0.94

* Average specific consumption of diamond exceeds the norm.

** Tool diameter 1000 mm.

*** Double-row tool diameter 510 mm.

For milling with a double-row tool of diameter 510 mm the variance in specific powder consumption (Fig. 2) is higher than for single-row plate tools, whereas the average specific consumption is around 1.43 carats/dm^3.

Rough grinding of parts made of glasses LK105, K100, and K108 removing 1.0 – 1.5 mm off the treated surface, apart from the above described single-row plate-like wheel, was also performed using a tool based on spots. Elements of

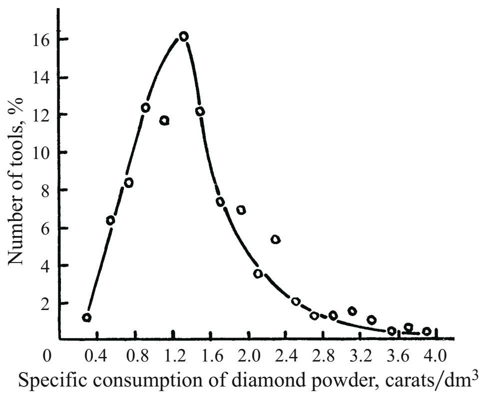

Fig. 2. Normal distribution density curve of diamond specific consumption in milling using a double-row wheel on plates AS15/AS20 of grain size 315/200 and concentration 100% ; AS15 of grain size 160 – 125 and concentration 50%.

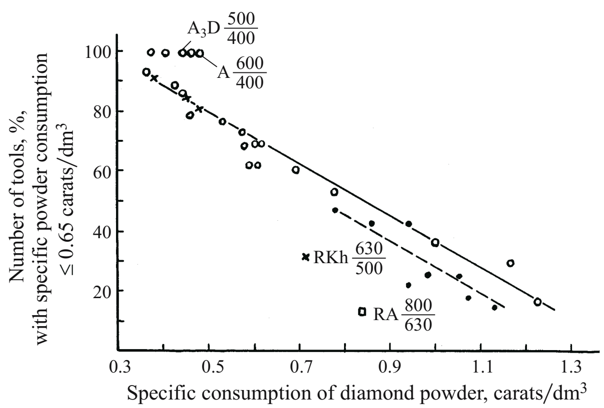

Fig. 3. Dependence of the share of tools with specific diamond consumption within 0.65 carats/dm^3 on their average specific consumption for plate-like single-row tools of diameters 566 – 510 mm (○) and 350 – 200 mm (×) and spot-like wheel of diameter 510 mm (●). For the points that do not coincide with the curves, powder grade and grain size are specified.

diameter 16 × 5 mm were placed along the peripheral zone of the faceplate on the polished side of the cylinder, whose axis is directed to the center of the wheel base. The principle of making this grinding wheel is similar to the one described for the plate-based wheel. The space factor of the working zone changes, as the cylinder gets worn, and is equal to 0.2 and less along its radial section. The average specific consumption for the reference composition with diamond powder AS15 of grain size 160/125 and concentration 50% is equivalent when passing from binder M1-1 to binder M3-12 according to TU 3-037–83 (32% copper, 40% powdered aluminum, 18% zinc, 5% crystalline silicon, 5% baddeleyite powder). The obtained results are listed in Table 2.

On passing to stronger diamonds (AS20, AS50) of smaller grain size (100/80), the mean specific consumption of powder decreases by 24% and for diamond powder AS32 by 31%. The variance of specific consumption values for the three most commonly used compositions are shown in

TABLE 2

Diamond powder*		Number of tools considered, units	Specific consumption of diamond powder, carats/dm^3	
grade	grain size		average	range
		Binder M1-1		
AS15	160/125	11	1.07	0.16 – 2.25
AS20	160/125	4	0.97	0.37 – 1.22
RKh1	160/125	8	1.05	0.40 – 2.01
		Binder M3-12		
AS15	160/125	61	1.13	0.26 – 2.50
AS20	160/125	116	0.98	0.33 – 2.55
AS32	160/125	70	0.78	0.40 – 1.90
AS50	160/125	7	0.94	0.36 – 1.56
AS15	100/80	28	0.86	0.22 – 2.70
AS20	100/80	14	0.94	0.52 – 2.20

* Concentration 50%.

Fig. 1*d*. The shape of the variance curves and specific consumption values differ from the data in Fig. 1*a* – *c* for plate tools; at the same time, the element shapes and binders are different and the grain size of diamond powders is lower by 4 classes.

It can be seen from Fig. 3 that for the plate-like single-row tool the percent of specific diamond consumption within 0.65 carats/dm^3 decreases nearly linearly in the entire range of sizes (566 – 200 mm) and powder compositions, as the average specific consumption of powder grows. Certain deviations are observed for the milling tool using recuperated diamond powder of coarse grains (RKh, 630/500) and in the range of minimal average consumption values (0.36 – 0.46 carats/dm^3), namely, for a small number of used grinding tools (7 – 13 units) all specific consumption data for some compositions are below 0.65 carats/dm^3. A similar dependence is observed for tools based on spot-like elements. However, their mean specific consumption are within the maximum value range for wheels with plate-like elements, and, accordingly, the percent of diamond consumption within the prescribed standard value is lower.

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